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CHARACTERIZATION OF ANTITANK FIRING RANGES
AT CFB VALCARTIER, WATC WAINWRIGHT AND
CFAD DUNDURN

by

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T.F. Jenkins, M.E. Walsh, P.G. Thorne, and T.A. Ranney, CRREL

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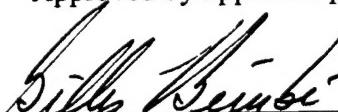
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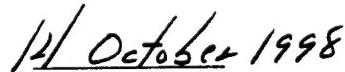
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ABSTRACT

Some operational activities of the Canadian Forces such as firing practice may cause the dispersion of energetic compounds in the environment. These compounds should be closely monitored due to their highly specific physical, chemical and toxicological properties. In Canada, limited effort has been spent to examine this particular environmental threat. In this context, the characterization of many firing ranges potentially contaminated with explosives has been performed during the last few years. Air-to-ground ranges and ground-to-ground ranges have been characterized and, in general, low levels of multi-contamination by explosives were found. However, antitank firing ranges sampled showed high levels of contamination by HMX, a high explosive used in many antitank rockets. This report details the characterization of five antitank ranges located at Canadian Forces Base Valcartier, Western Area Training Center Wainwright and Canadian Forces Ammunition Depot, Dundurn. The sampling and analytical methods are described and the results are presented. This work should help the Canadian Forces to pursue their operational activities, while minimizing the impacts on the environment by providing a better comprehension of the source of contamination and helping to minimize the environmental impacts in the future.

RÉSUMÉ

Certaines activités des Forces canadiennes comme les exercices de tirs peuvent entraîner la dispersion de composés énergétiques dans l'environnement. Ces composés représentent autant de contaminants pour l'environnement, car ils possèdent des propriétés particulières, du point de vue physique, chimique et toxicologique. Au Canada, cette menace environnementale n'a pas été vraiment envisagée et elle a été très peu documentée. Dans ce contexte, on a procédé à la caractérisation de plusieurs sites de tir potentiellement contaminés aux explosifs. Divers sites de tir air-sol et sol-sol ont été caractérisés et, de manière générale, on a trouvé de la multi-contamination faible par plusieurs explosifs. Cependant, on a retrouvé de fortes concentrations de HMX, explosif présent dans plusieurs armes anti-char, sur les sites où ces armes sont utilisées. Ce rapport décrit les caractérisations effectuées sur cinq sites de tir à la base des Forces canadiennes de Valcartier, au Centre d'entraînement de la région de l'Ouest des Forces armées à Wainwright et au dépôt de munitions de Dundurn. Les méthodes d'analyse et d'échantillonnage sont décrites et les résultats obtenus sont présentés. Ce travail permettra aux Forces canadiennes de poursuivre cette activité opérationnelle tout en minimisant les impacts environnementaux futurs grâce à une meilleure compréhension de la source de contamination.

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EXECUTIVE SUMMARY

Identifying and developing economical and effective methods to eliminate undesirable contaminants from the soil and groundwater are of increasing worldwide interest and importance to the environment. The task is all the more critical and complex when the contaminants are energetic materials, which are the main components of explosives and propellants. Energetic compounds are just now being recognized as environmental contaminants compared to other contaminants such as heavy metals, petroleum compounds or organic solvents. They are also unique of concern, because of their specific chemical, physical and toxicological properties. A new international context emerged with the end of the Cold War, the closing of military bases and a growing environmental awareness. This has led the Defence Research and Development Branch to devote some of its resources at acquiring the necessary expertise and technologies to support the Department of National Defence (DND) and the Canadian industry in finding practical, economical and effective solutions to the characterization and remediation of explosives-contaminated sites. It is one of the DND's objectives to implement environmentally benign defence activities. This involves scrutinizing all defence activities to ensure that they have no adverse impact on the surrounding environment. It is within this context, and also within the context of base closures and demilitarization, that the Defence Research Establishment Valcartier (DREV) initiated five years ago an R&D program to study the environmental impacts of energetic materials, specifically those found in the Canadian Forces (CF) ammunition stockpile. Activities such as firing exercises, demolition procedures and destruction of out-of-specification ammunition can lead to the dispersion of energetic compounds in the environment.

This report presents the results obtained from the characterization of operational firing ranges, more specifically of antitank firing ranges. The ammunition system used on these sites led to the dispersion of energetic materials in the environment, mainly from the melt-cast explosive included in the firing system, Octol based on trinitrotoluene (TNT) and cyclo-1,3,5,7 tetramethylene-2,4,6,8 tetranitramine (HMX). High levels of HMX can be found on the surface soil of these sites, while TNT is suspected to leach to the groundwater table. Five different firing ranges were sampled and conclusions are drawn on the source of contamination and on the ways to minimize this impact in the future. Furthermore, another R&D effort has led to the development of a technology which now offers a remedial action for these contaminated sites.

The overall work described in this report will help DND to assess the environmental impacts of this activity and will provide critical information to establish future operational requirements and procedures. More specifically, it will help DND to pursue this operational activity while minimizing the adverse impact on the environment.

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NOMENCLATURE

ACN	Acetonitrile
2-ADNT	2-amino-4,6-dinitrotoluene
4-ADNT	4-amino-2,6-dinitrotoluene
ATR	Antitank range
CFAD Dundurn	Canadian Forces Ammunition Depot, Dundurn
CFB Valcartier	Canadian Forces Base Valcartier
CRREL	Cold Regions Research and Engineering Laboratory
2,4-DANT	2,4-diamino-6-nitrotoluene
2,6-DANT	2,6-diamino-4-nitrotoluene
DNB	Dinitrobenzene
DND	Department of National Defence
DREV	Defence Research Establishment Valcartier
2,4-DNT	2,4-Dinitrotoluene
2,6-DNT	2,6-Dinitrotoluene
HMX	Cyclo 1,3,5,7-tetramethylene-2,4,6,8 tetranitramine
HPLC	High pressure liquid chromatography
NB	Nitrobenzene
NC	Nitrocellulose
NG	Nitroglycerine
nm	Nanometer
2-NT, 3-NT, 4-NT	2-nitrotoluene, 3-nitrotoluene, 4-nitrotoluene

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NOMENCLATURE

RDX	Cyclo-1,3,5-trimethylene-2,4,6-trinitramine
R&D	Research and Development
TNB	Trinitrobenzene
TNT	Trinitrotoluene
WATC Wainwright	Western Area Training Center, Wainwright

1.0 INTRODUCTION

Identifying and developing economical and effective methods to eliminate undesirable contaminants from the soil and groundwater is of increasing worldwide environmental interest and importance. The task is all the more critical and complicated when the contaminants are energetic materials, which are the main components of gun powders, explosive warheads and solid rocket propellants. Even if site characterization has been well documented over the last twenty years, only little is known about the environmental behaviour of energetic compounds. The new international context with the end of the Cold War has resulted in the closing of many military bases and a growing awareness in environmental issues. This awareness has led many countries to integrate R&D programs related to the environmental impacts of energetic materials. Over the last ten years a large effort have been dedicated internationally on the characterization of the extent of explosives contamination on a large number of ammunition plants and military depots (Refs. 1-4). Some of these facilities have produced military-grade explosives while others have conducted load, assemble and pack operations, with explosives supplied from production facilities. Some military depots have also been found to have significant levels of contamination as well. The source of this contamination was often the disposal of off-specification material and the demilitarization of out-of-date munitions. In both cases, the contaminants most often observed were TNT (2,4,6-trinitrotoluene), RDX (1,3,5-hexahydro-1,3,5-trinitrotriazine) and their manufacturing impurities, and environmental transformation products (Ref. 5). More recently, a detailed protocol for the characterization of sites contaminated by explosives have been published: it covers all pertinent aspects of site characterization and will serve as a reference guide in future samplings of explosives-contaminated sites (Ref. 6). This effort was justified by the potential negative health and environmental impact of energetic materials.

In a general effort to assess the environmental impacts of the Canadian Forces operational activities, many air to ground and ground to ground firing ranges have been characterized by DREV scientists. In general, low levels of multi-contamination by explosives were found, demonstrating that the detonation of ammunition is a relatively clean process, which leads to a minimal impact on the environment. However, an exception was encountered at a Canadian antitank firing range where high levels of HMX were found in the surface soils (Refs. 7-9). Similar results were obtained on a U.S. antitank firing range recently characterized (Ref. 10).

An effort was then dedicated to address the specific characterization of antitank firing ranges. This report presents the results obtained from the characterization of five different antitank firing ranges located at three sites: Canadian Force Base Valcartier (CFB Valcartier), Western Area Training Center, Wainwright (WATC Wainwright) and Canadian Forces Ammunition Depot, Dundurn (CFAD Dundurn). The first identification of the presence of high levels of HMX was performed in May 1995 at CFB Valcartier. This site was then re-sampled twice to better understand the extent of the contamination. The third sampling campaign was performed in close collaboration with Cold Regions Research and Engineering Laboratory (CRREL) scientists.

This work was carried out between May 1995 and December 1997 under WU 2ef11, "Characterization of DND Sites Contaminated with Energetic Materials" and co-sponsored by a task coming from the Directorate General Environment (DGE) through the Directorate of Ammunition Program Management (DAPM).

2.0 RANGES HISTORIC/DESCRIPTION

Five antitank ranges were sampled between May 1995 and September 1997. The antitank range at CFB Valcartier was sampled three times in May 1995, October 1995 and September 1996 and the last sampling activity was performed in collaboration with CRREL scientists. The four remaining antitank ranges were sampled from September 15th to September 22nd. Two ranges were sampled at Canadian Force Western Area Training Center Wainwright (WATC Wainwright) in Alberta, Ranges 13 and 22 and two at Canadian Forces Ammunition Depot, Dundurn (CFAD Dundurn) in Saskatchewan, Ranges 2 and Cougar Range. Pictures of these five ranges can be found in Figs. 2 to 7.

These five ranges differ in location, frequency of use, soil type and hydrogeology. In each site the extent of surface soil contamination was assessed. Moreover, limited drilling operations with collection of groundwater samples and running surface water samples were carried out at CFB Valcartier. The spatial heterogeneity of the dispersion of HMX in the surface soil was also carefully studied (Refs. 7-9). The main weapon system used on these ranges is the 66-mm M72 light antitank rocket system. This weapon system is of U.S. design and is manufactured in Norway (Ref. 11). The body of this rocket contains the copper, shaped charge liner backed by a melt-cast filling of

approximately 0.3 kg of Octol (Fig. 1). The melt cast explosive Octol is composed of a mixture of HMX and TNT in a 70:30% ratio by weight (Ref. 12).

2.1 Arnhem antitank firing range, CFB Valcartier.

CFB Valcartier is the largest CF land base in Canada. Many air to ground and ground to ground firing ranges are frequently used there for operational training, including the Arnhem antitank firing range (ATR). This range is about 100 hectares in size and has four target tanks. The first two targets are in a fairly level region of the site near the access road, labeled C and D. This area is sparsely vegetated, being regularly burned by CF troops to limit the growing of grass and the ignition of secondary fires. The soil is sandy and well drained with a groundwater table at a depth of 12 feet. The two other target tanks (labeled A and B) are located on a rocky hill behind Tanks C and D at different distances from the firing point, as shown in Fig. 8. These two targets are located on rock with a thin top soil layer covered with grass. Metallic shrapnel is dispersed over the site, mostly nearby the four targets. This site is an active firing range and has been in use all year long for the last 20 years and M72 weapons are fired on a routine basis.

2.2 WATC Wainwright

WATC Wainwright is the training center for all CF bases of Western Canada, and present many firing ranges that serve for the training of CF troops and allied forces troops. Two major antitank firing ranges are used, Ranges 13 and 22. Both ranges are very large and present many target tanks. The soil there is rather basic since in that particular area, it contains high levels of potash. The soil consists of sandy loams and is covered by prairie-grass.

Range 13 is the most used antitank range in Canada. Seven target tanks are located on this 4 km^2 site. It is used on a daily basis almost all year long by the Canadian Forces but also by international allied forces such as the British Forces, USA and Italy. The range has been in use since the Second World War and the main ammunitions fired there today are 66 mm-M72, with occasional firings of 84 mm and 105 mm, which are also filled with Octol.

Range 22 is as large as Range 13 and also presents seven targets. The soil type is the same as at Range 13 and is also grass covered. Range 22 is less used than Range 13. However, one month before our visit, Range 22 was used to fire M72 to calculate their "dudding" rate; two hundred and twenty units of M72 were fired, which produced one hundred and five duds.

2.3 CFAD Dundurn

CFAD Dundurn is the largest ammunition depot in Canada. It presents a few training ranges still in use during summertime on a non-daily basis. This site is used mainly for the destruction of out-of-specification material by open burning open detonation, while firing activities are rarely carried out at the present time. However, during the second World War, these training ranges were fully operational. Two antitank firing ranges were sampled: Range 2 and Cougar Range.

Range 2 has been used extensively in the past (first used in 1945), but not on a frequent basis since 1970. It is now used for the firing of 66- and 84-mm antitank weapons. It measures approximately 1 km² and consists of a sandy loam. The area is rolling prairies, roughly leveled but with knolls reaching up to 5 m. There is vegetation everywhere, consisting mainly of prairie grass, 0.3 to 0.4 m in height. There are three target areas consisting of two tanks and a car. These three target areas have been in use only since 1994, since the site layout was modified at that time with new target positions. The old target positions were unfortunately impossible to locate.

The Dundurn Cougar range is about 1 km² and has not been used for many years. This site was used in the past but since 1970 it is used only during the summer, on a non-daily basis. The site presents five targets at long distances from the firing pit. It presents exactly the same soil type and description of Range 2.

3.0 SAMPLING STRATEGY

The sampling strategy that was taken at each sites differed depending upon the type of soil, type of vegetation and the goal of the sampling. CFB Arnhem antitank Range was sampled three times, each time with a different goal. This site allowed the possibility of establishing gridding pattern to perform a systematic sampling since no vegetation was

present at the lower part of the range. Also, since a Level 2 clearance was done prior to the second sampling, it was possible to drill at various depths to establish the depth profile of HMX contamination. At the opposite, the four other antitank ranges sampled were not cleared before our visit and therefore only surface sampling was allowed on these sites with the presence of a CF ammunition specialist at all times during the sampling to ensure the safety of the team, as recommended in Ref. 6.

3.1 CFB Arnhem Antitank Range

The Arnhem antitank range was sampled on three occasions in May 1995, October 1995 and September 1996. The last sampling was performed in collaboration with CRREL scientists.

3.1.1 First Sampling/May 1995

The first sampling of Arnhem antitank range was performed in May 1995 in an overall sampling campaign of various firing ranges at CFB Valcartier. It was in this first sampling event that the identification of contamination by HMX was assessed on a Canadian antitank range. For this first sampling, a limited number of 16 samples were collected with four collected around each target labeled A, B, C and D (Fig. 8). The strategy consisted in collecting composite samples at a mean distance of 2 m from the targets in the four directions. The samples were labeled from 1 to 4, depending if they were collected westwards, northwards, eastwards or southwards from the targets. Consequently, 16 samples were taken and labeled from A1 to D4. Each composite sample consisted of 10 sub-samples taken randomly at a mean distance of 2 m from the targets in each direction.

3.1.2 Second Sampling/October 1995

The second sampling, in October 1995, was performed in order to assess the depth profile of the HMX contamination. Prior to the sampling, a Level 2 clearance was performed on a limited portion of the site nearby tank labeled D to allow for safe drilling operations. The sampling was limited to the surroundings of Target D, as shown in Fig. 8. Seven locations were sampled at three different depths, depending of the clearance level and the proximity of the target.

Well # 1 was located 15 m south of Target D and was sampled at various depths down to 33 feet. The groundwater table was reached there at 12 feet depth and the well was installed for the collection of groundwater samples. The samples were labeled 1-x', where x represents the mean depth at which they were collected. Four locations were drilled 2 m from the target westwards (labeled 2), southwestward (labeled 3), southeastwards (labeled 4) and eastwards (labeled 5). Each of these four wells were sampled at surface and at each foot for three feet. The samples were labeled 2, 3, 4 or 5-surface or 2, 3, 4 and 5-x', where x represents the mean depth at which they were collected. Finally, the two last locations were labeled Wells 6 and 7 and were located 4 m from the target, southwestwards (#6) and southeastwards (#7). They were drilled at a depth of ten feet and sampled at surface, 1, 2, 4, 6, 8 and 10 feet. The samples were labeled 6 or 7-surface or 6 or 7-x', where x represents the mean depth at which they were collected.

3.1.3 Third Sampling/September 1996

The objective of this last sampling campaign was fourfold. The first part was to assess the degree of short-range heterogeneity of this HMX-contaminated range, with respect to that found on other types of explosives-contaminated sites. The second one was to assess the utility of on-site analytical methods for HMX and TNT. Thirdly, the use of a simple compositing approach was evaluated for obtaining representative samples within grids. Finally, the levels of accumulation of HMX and TNT on this range were determined. The three first objectives were fully achieved and are documented in Refs. 7 to 9.

The strategy used in this sampling activity was based on a preliminary evaluation of the short-range heterogeneity and depth of contamination and was strongly based upon the results obtained with the colorimetric field method (Refs. 7-9). The area around Tank D and extending to Tank C was divided into 6 m by 6 m grids labeled D1 through D11 and C4 through C10, and each grid was sub-divided into four 3 m by 3 m sub-grids, as shown in Fig. 9. The sub-grids were labeled A to D, starting with A in the upper left corner and going to D clockwise. Composite samples to form area integrated samples were taken, such as described in Ref. 8. The samples were labeled "area integrated" since they represented the entire circular area sampled. Weighted portions from each of the four

area integrated sub-grids samples from within a grid were combined and homogenized in duplicates to prepare the composite samples to represent each grids.

Within this third event, water samples were collected at four locations: in monitoring Well 1, in two stagnant water ponds formed by impact craters in the rocky cliff nearby targets labeled A and B (surface waters 1 and 2) and finally in a larger pond located at about 0.5 km south of the site across the access road (surface water 3). The sampling of the well and sample treatments were carried out as prescribed in Ref. 6.

3.2 WATC Wainwright

No clearance has been performed on the ranges sampled at WATC Wainwright either prior to our sampling or even in the year before. Consequently, we were authorized to sample only the surface soils and no data are available on the depth profile of the contamination. Moreover, the presence of a thick layer of prairie grass on the sites did not allow to build systematic grids as for Arnhem range, except for a small area in front of the tank labeled 3 at Range 13.

The sampling strategy was then to take composite samples in front of (labeled A) and behind (labeled B) the main target tanks. Each composite samples were built out of 15 sub-samples taken randomly in front of and behind the targets. Only one limited gridding pattern was allowed in front of Target 3 at Range 13 at WATC Wainwright, since there was no vegetation in that particular area.

3.2.1 Range 13, WATC Wainwright

The seven target tanks were labeled from 0 to 6 and Tank 2 was not sampled since it has not been used as a target for many years (Fig. 10). The soils in front of and behind the tanks labeled 0 to 6 were sampled (0A-6B), and samples 3.5 and 4.5 were taken between targets 3 - 4 and 4 - 5. The soil in front of Tank 3 was sampled more thoroughly since it was not grass covered and also because it was the preferred target (Fig.11). Firstly, sample 3AA was taken in front of Tank 3 at a distance of 15 m. Then, a 4 m wide grid was installed in front of it, centered with Tank 3 and split into two 2 m alleys. These alleys were sampled at each 6 m from 0 to 36 m away from the target. Twelve samples (3G1 to 3G12) were taken (2 x 6 grids) in front of tank 3. Samples 3G1, 3, 5, 7, 9, and 11

were taken in the right alley, while samples 3G2, 4, 6, 8, 10 and 12 were taken in the left one. Each of the 3G samples was built out of 10 sub-samples within each sub-grid. Tank 3 is located at the top of a small hill in the middle of the range and therefore represents the preferred target. There is a declination of about 40 ° from Samples 3G1 and 3G2 to Samples 3G11 and 3G12. Samples 3G11 and 3G12 were taken in a soil covered with grass at the bottom of this small hill. Many duds and leaching broken casing were found in front of and behind this particular target. The samples were labeled WATR13, 0A to 6B and the grid samples were labeled WATR13 -3G1 to 3G12.

3.2.2 Range 22, WATC Wainwright:

The seven target tanks were labeled from 1 to 7 (Fig. 12). Target tanks labeled 1, 3, 4, and 7 were sampled in front of and behind targets with composite samples built of 20 sub-samples. Target tanks labeled 2, 5 and 6 were not sampled since they were obviously less used. The samples were labeled WATR22-1A to WATR22-7B.

3.3 CFAD Dundurn

As for WATC Wainwright, no clearance has been performed on the ranges sampled at CFAD Dundurn either prior to our sampling or even in the year before. Consequently, we were authorized to sample only surface soils and no data on the depth of contamination are available. Moreover, the presence of a thick layer of prairie grass on the sites did not allow to build systematic grids either. The sampling strategy was then to take composite samples around the main target tanks. Each circular composite sample was built out of 15 sub-samples taken randomly in a circular pattern around the targets at a mean distance of 1-2 m from targets.

3.3.1 Range 2 , CFAD Dundurn:

The soil around the three target tanks (Fig. 13) was sampled in a circular pattern with a radius of 3 m with the target in the center. Composite samples were built with 20 sub-samples taken randomly in the circular area around the target. The samples were labeled DDATR2- 1 to DDATR2- 3.

3.3.2 Cougar range, CFAD Dundurn

The soil around four of the five targets (Fig. 14) was sampled as for Range 2 with a circular pattern. The samples were labeled DDCR-1 to DDCR-5. Target 4 was not sampled since it was far away from the firing pit and there was no shrapnel nearby the target, indicating that it had not been used for many years.

4.0 EXPERIMENTAL

Samples were collected by DREV's team at CFB Valcartier (first two events), at WATC Wainwright and CFAD Dundurn. They were collected by the DREV and CRREL teams during the third event at CFB Valcartier. The samples were analyzed at DREV for the first two samplings at CFB Valcartier and the samples collected during the third event were analyzed both at CRREL and at an independent commercial laboratory. The samples collected at WATC Wainwright and CFAD Dundurn were sent for analysis to a commercial laboratory with some samples analyzed at DREV for quality control. Commercially available field screening methods were used during the third sampling event at CFB Valcartier (both enzyme immunoassay and colorimetric methods) and the colorimetric method was used at WATC Wainwright and CFAD Dundurn.

4.1 *Chemicals and Equipment*

All standards for explosives analytes were obtained from Accustandard, standards for EPA 8330 method (Ref. 13). All acetone used for soil extraction, homogenization of soil samples and glassware cleaning was reagent grade and was obtained from Anachemia. The methanol used in the laboratory for preparation of HPLC eluents was Sigma-Aldrich HPLC grade. Deionized water was used in the field for cleaning and for addition in acetone extracts. Laboratory grade water used for preparation of HPLC eluents was obtained from a Millipore Milli-Q Type 1 reagent grade water system at DREV. Reagent grade chemicals were used to perform the salting-out procedure for water samples. HPLC laboratory analyses performed at DREV were done with a HP Model 1090 equipped with a diode array UV detector HP Model 1100. HPLC laboratory analysis at CRREL were performed using a LC-CN column (Supelco) eluted with 1:1 methanol-water at 1.2 ml/min. Absorbance was recorded at 254 nm on a spectra-physics

Model 8490 variable wavelength detector and peak were recorded on a Hewlett-Packard 3396 Digital integrator operated in the peak height mode. Field screening colorimetric test kits used for HMX and TNT were obtained from Ensys. External laboratory analytical services were performed by Philips Inc.

4.2 Sample Treatment and Laboratory Analysis

For all sampling campaigns conducted at CFB Valcartier, the soil samples were kept cold and in the dark until processed. The processing was conducted either the same day the soils were collected or the following morning. Individual soil samples in Ziploc bags were shaken and kneaded and then emptied in aluminum pans. The soils were further homogenized by breaking up clumps with gloved hands and stirring. For the two first sampling events, the soils were extracted with acetonitrile by sonication, as described in the EPA method (Ref. 13). For the third event, the soils were extracted with acetone (20 g / 100 ml) in a vortex mixer for 30 minutes. The extracts were allowed to settle and a 50 ml fraction of supernatant filtered through a Millex SR filter membrane. The acetone extracts were subsequently returned to CRREL and analyzed using RP-HPLC separations similar to those described in Method 8330. Some extracts were also analyzed with Gas chromatography (Ref. 8). Separate portions of the soil samples were sent to an independent laboratory for analysis with Method 8330.

For the sampling events of WATC Wainwright and CFAD Dundurn, the soils samples were collected, kept cold, in the dark and frozen on the same day. The frozen samples were sent by express mail to an external laboratory for analysis with Method 8330, following recommendations on pre-homogenization (Ref. 6).

4.3 Field Screening Methods

Field screening methods were used at the third sampling event at CFB Valcartier and at WATC Wainwright and CFAD Dundurn. Both colorimetric and immunoassay field screening methods were used at CFB Valcartier, while only the more applicable colorimetric method was used at WATC Wainwright and CFAD Dundurn. Complete details regarding the applicability and results of the field screening methods obtained at CFB Valcartier can be found in Ref. 8. They will not be discussed in this report. The

colorimetric method was found to be the best to use with an excellent correlation with the laboratory methods. At WATC Wainwright, the colorimetric method did not lead to quantitative results due to the presence of nitrocellulose (NC) as a co-contaminant in these soil samples, which interfered. However, the method gave semi-quantitative results and indicated high concentrations of HMX in many of the samples. At CFAD Dundurn, the colorimetric method was applicable and led to an excellent correlation between the data obtained both with the field and the laboratory method.

5.0 RESULTS

The results are reported for each site separately. Areal and vertical extent of contamination, spatial heterogeneity and QA/QC applied are discussed.

5.1 CFB Valcartier

Only RDX, TNT and HMX were quantified in the first two sampling events since they were carried out only to detect the presence of one of these three explosive residues. On the third sampling event, all the explosive residues detected with Method 8330 were quantified.

5.1.1 First Sampling, May 1995

The results obtained during this first sampling event are reported in Table I. The sixteen samples collected show high levels of HMX, with concentrations ranging from 16 to almost 3900 mg/kg. Almost all samples were co-contaminated by RDX, which is present as a production impurity in HMX, but to a much smaller extent, with concentrations ranging from non-detectable level to 11.5 mg/kg. TNT contamination was detected in almost all samples, except for sample C2. The TNT concentrations did show a correlation with the HMX concentration found, but not in the ratio that we could have expected (30:70%), based on the melt-cast Octol formulation (Ref. 12). The ratio observed between the HMX and TNT concentrations were much lower than expected, probably due to a rapid leaching of more soluble TNT in the sandy soils. This first sampling demonstrated that the Arnhem antitank Range was contaminated mainly by HMX, at high levels.

5.1.2 Second Sampling, October 1995

The results obtained during this sampling event are reported in Table II. The samples collected from Well 1, located at a distance of 15 feet south of Target D show no contamination by either HMX or TNT and only two samples at the surface and 30 feet down show the presence of low levels of RDX. The samples collected from Wells 2, 3, 4 and 5, all located at a distance of 2 m from Target D, show high levels of contamination by HMX at the surface, with concentrations over 800 mg/kg. The depth profile of HMX contamination decrease very rapidly with a mean of 100 times lower concentrations at only one foot deep in comparison with the surface samples. Except for Well 5, no contamination is detected at 3 feet deep. Wells 6 and 7, located at a distance of 4 m from the target showed lower surface contamination by HMX and no depth contamination.

This second sampling event showed that the areal distribution of HMX contamination is strongly related to the target position and also that the vertical profile of contamination is simple with high levels of HMX at the surface with a rapid decrease of contamination as a function of depth.

5.1.3 Third Sampling, September 1996

The results of this third sampling event obtained by field screening methods, RP-HPLC methods on acetone extracts and Method 8330 are discussed in detail in other documents (Refs. 6-9). However, the results for HMX concentrations detected by Method 8330 are presented in Fig. 9. Also, the results for each grid and sub-grid obtained with the same method are presented in Tables III to XVIII .

Two conclusions can be drawn from the results presented in Fig. 9. First, the areal distribution of HMX shows a great correlation with the target positions and higher HMX concentrations are found near the targets. Grids C4, C5, C6, D2, D8 and D4 show the highest concentrations of HMX and are all located near Targets C and D. The concentrations of HMX decrease rapidly in the grids farther targets. Secondly, the mathematical means of sub-grids show a very good correlation with the composite samples built from the sub-samples of sub-grids within a grid, demonstrating that the sampling method used lead to representative results of the area sampled.

The results presented in Tables III to XVIII present all explosives residues detected by Method 8330. On the sites contaminated with TNT, the co-contaminants may include biotransformation products such as 2-amino-dinitrotoluene (2-A-DNT) and 4-amino-dinitrotoluene (4-A-DNT), photodegradation products such as trinitrobenzene (TNB) and manufacturing by-products such as dinitrotoluene (DNT) and dinitrobenzene (DNB). In several of the grids sampled, we found both isomers of amino-DNT, indicating that biotransformation of TNT is taking place and this process is likely to contribute to much lower concentrations of TNT compared with HMX. The highest concentrations of the amino-DNTs were about 10 mg/kg behind Tank D, grid D7, where the soil was moist and appeared to have a higher organic content. Elsewhere, the amino-TNTs were generally in the 1-2 mg/kg range. Soil analyses revealed only traces of RDX, in comparison with the levels of HMX. Often, the concentrations of RDX were less than method detection limits and were almost always under 2 mg/kg. If RDX was present as a production impurity in HMX, it is suspected to have leached at a faster rate than less soluble HMX.

In a general pattern, for all samples collected, the TNT concentrations are found to a much smaller extent than what could have been expected, on the basis of the HMX:TNT ratio of the Octol melt-cast explosive used on this site. None of the sample collected showed levels of TNT in accordance with the 70:30% HMX:TNT ratio of Octol. The presence of amino-DNTs on the site proved that biotransformation of TNT took place there and these more leachable metabolites and TNT have leached more rapidly than HMX, leading thus to lower concentrations in the surface soils.

5.1.4 Water Analysis

We also found high concentrations of HMX in the few water samples collected at CFB Valcartier (Table XIX). The highest HMX concentration was in the well water (295 µg/L). The TNT concentrations were about 100 times lower than those of HMX, a similar ratio to what was observed in the soils. The concentration ratio of HMX to RDX in the well water is approximately 6; however we only sporadically found RDX in soils. This might indicate that RDX have leached more rapidly than HMX and is more concentrated in groundwater. This might be partially confirmed with the result obtained from Surface Water 3, which was collected at a distance of 0.5 km from the site. There, the RDX concentration is about seventh times the HMX concentration. This could be explained by the higher dissolution rate and solubility of RDX which will go farther than

HMX more rapidly. Again, no TNT is detected in this sample. TNT is either farther than that or have been biotransformed and/or bound to the soil matrix. These overall results could be compared with a giant chromatographic process once the analytes are dissolved. HMX is retained the most and stays near the surface due to slow dissolution and low solubility. RDX is leached through the soil, groundwater and have reached at least a 0.5 km radius of dispersion. TNT is either farther than that or more probably retained or transformed into metabolites in the environment. This situation will have to be examined more thoroughly, to better understand the relative environmental fate of TNT, RDX and HMX.

5.2 **WATC Wainwright**

5.2.1 Range 13, Wainwright

Table XX shows high HMX concentrations near the target tanks. Often, the concentration found behind the targets (labeled B) is higher than that in front of the targets (labeled A). This might appear strange but it can be easily explained by the fact that all targets were heavily perforated and therefore, the fired weapons could easily pass through the target and produce duds behind them. The concentrations of HMX range from non-detectable to 3700 mg/kg. High concentrations of HMX are found near the targets and as soon as samples are taken far from target, such as samples 3.5 and 4.5, concentrations of HMX decrease rapidly. Higher concentrations are also found near the most used targets. The concentrations decrease rapidly from the target even with a declination from the target to the bottom of a hill (samples 3G1 to 3G12, Table XXI). We can see on this range that the situation is similar to Arnhem ATR, with TNT concentrations that do not reflect the 70:30 ratio of Octol. There is an exception for sample 3AA where the ratio HMX:TNT is 80:20%. It has to be mentioned that a broken M72 casing was found in the area where this sample was collected. This is a very interesting result since it may explain why in that specific case higher levels of TNT are found, it would be still in the surface soil, being liberated in the environment only recently.

Tetryl was also found in many samples at a lower extent with concentrations lower than 20 mg/kg. The presence of tetryl on this site may be attributed to the firing of other weapon systems, including this high explosive. Tetryl was used in the manufacture

of primary and secondary charges for blasting caps and older version of M72 included this chemical (Ref. 14).

5.2.2 Range 22, Wainwright

The HMX concentrations found on Range 22 are lower than those found at Range 13, which is not surprising since it is not used as heavily as range 13 (Table XXII). The concentrations measured could be related with the trial carried out at this range a month prior to sampling (dud rate calculation). RDX and TNT are found at lower concentrations, ranging from non-detectable to 2.2 mg/kg, except for sample 1B where TNT is detected at higher levels. Again here, a broken M72 casing with leaching Octol was located in the sampling area.

For both ranges, the colorimetric method was used but led to only semi-quantitative results, since an interference attributable to nitrocellulose (NC) prevent obtaining quantitative results.

5.3 CFAD Dundurn

5.3.1 Range 2 and Cougar Range, Dundurn

Both ranges (Tables XXIII and XXIV) show low concentrations of HMX, with the highest result at 120 ppm. This correlates the fact that these two ranges are not used frequently and also that the target locations have been changed in 1994. For these ranges, the colorimetric method was used and the results obtained in the field are reported in table XXIII and XXIV. The results obtained in the field correlate very well with those obtained in the laboratory for RDX and HMX.

5.4 Comparative Results

The soil samples from all the installations were analyzed using SW846 Method 8330. HMX was the residue detected at highest concentration in all cases; maximum concentrations of HMX in the surface soils were 2100 mg/kg, 3700 mg/kg, and 120 mg/kg for CFB-Valcartier, WATC-Wainwright and CFAD-Dundurn, respectively. A

general correlation between the intensity/frequency of use of ranges for firing can be established on the basis of our results. The results from CFAD Dundurn sampling show a lesser degree of contamination (< 120 mg/kg) which correlates with a lesser frequency of firing practice on these ranges in the past few years. At the opposite, the most used antitank firing range in Canada at WATC Wainwright shows the higher degree of contamination, with HMX concentration as high as 3700 mg/kg.

Other target analytes detected in soils from all the installations included RDX, TNT, and two environmental transformation products of TNT, 2-amino-4,6-dinitrotoluene (2ADNT) and 4-amino-2,6-dinitrotoluene (4ADNT). At WATC Wainwright, several soil samples had rather high concentrations of TNT (maximum detected was 880 mg/kg), but these soil samples were collected near ruptured munitions where the solid explosive had been spilled recently on the soil. In addition, two samples from CFAD Dundurn had RDX concentrations of 85 mg/kg and 89 mg/kg (possibly from A5 booster, see Fig. 1), but these were the only samples at any of the four installations with RDX concentrations above 20 mg/kg. Concentrations of target analytes, other than HMX, even in the surface soils near the targets, were generally below 10 mg/kg.

It is interesting to note that the concentration of HMX was almost always several orders of magnitude higher than TNT in the soils of all installations. This is surprising since the HMX at these sites originated from Octol, an explosive formulation which is composed of 70% HMX and 30% TNT. Clearly, there is an attenuation process in operation for TNT on these sites, which reduces its concentration relative to HMX, or TNT is more efficiently destroyed in the detonations than is HMX. We believe that TNT dissolves more rapidly in water and leaches into the soil profile, where it can be transformed and, perhaps, humified (Ref. 15). All the results obtained in this study have been recently correlated with another one performed at a US military installation on an antitank range (Fort Ord) in California (Ref. 10). This proves that the situation for soils found on Canadian antitank ranges is comparable to that on US antitank ranges, while the situation for the quality of the groundwater still has to be assessed.

5.5 Areal and Vertical Extent of Contamination

The concentrations of HMX in the surface soils from all the installations were strongly correlated with the placement of targets. Fig. 8 presents the mean concentration of HMX as a function of the distance from the target locations at CFB Valcartier.

There was also a marked gradient in HMX concentrations in soils as a function of depth. At CFB Valcartier, concentrations in the top 7.5 cm were a factor of 5 or greater than in soils from the 7.5-15 cm depth. An even greater concentration gradient was found at Ft. Ord (Ref. 10). For example, the mean concentrations of HMX in four soil profiles from a sampling grid next to a target location were as follows: 0-15 cm-295 mg/kg, 15-30 cm-1.7 mg/kg, 30-45 cm-0.6 mg/kg, 45-60 cm-0.4 mg/kg, and 105-120 cm-2.5 mg/kg. The concentrations of RDX, TNT, 2ADNT and 4ADNT were only detectable in the 0-15 cm depth samples. Overall, these findings demonstrate that the major residues of explosives at firing ranges are present in the surface soils near the target locations.

5.6 Spatial Heterogeneity

Spatial heterogeneity has proven to be a significant problem for site characterization at explosives-contaminated ammunition plants and depots. At CFB Valcartier, short-range heterogeneity was assessed by statistical treatment of the data and is described extensively in Ref. 8. The characterization of these samples used two independent analytical methods, showing that it was spatial heterogeneity, not poor analytical precision that caused the heterogeneity in the obtained results.

If site characterization at ranges is to provide reliable results, the sampling and analysis plans must address the large uncertainty imposed by the large spatial heterogeneity present at all scales. Compositing of discrete samples has proven to be effective at providing reliable estimates of mean concentrations for explosives-contaminated sites.

5.7 Utility of On-Site Methods

The soil samples from CFB Valcartier and Ft. Ord were analyzed using colorimetric-based on-site methods (Refs. 8 and 10). A method that was developed for

RDX was found to be very effective at estimating HMX concentrations for these soils. While the concentrations of TNT were much lower than those of HMX, a result from a colorimetric on-site method for TNT from EnSys provided estimates for TNT in agreement with those from SW846 Method 8330 at a much lower cost. This colorimetric on-site methods was also used at WATC Wainwright and CFAD Dundurn and provided an effective tool to assess the extent and localization of contamination by HMX.

5.8 QA/QC

A program of quality assurance and quality control was conducted within all the sampling campaigns. Field blanks were collected on each site, in the surrounding area representative of the ranges sampled. All field blanks showed no contamination by energetic compounds. In general, all the analyses were performed at least in duplicate or triplicates, whenever possible. When the analytical work was performed at DREV, 20% of the samples were sent to an external laboratory for confirmation. At the opposite, when the samples were sent to external laboratories, 20% of the samples were analyzed at DREV. A ratio of 10% of spiked and surrogates were included in the analytical work.

6.0 IDENTIFICATION OF THE CONTAMINATION SOURCE

The contamination source of HMX on these sites had to be determined. To achieve this, two separate actions were taken. First, the analysis of explosives residues remaining on metallic debris was conducted and, secondly, a dissolution kinetic experiment was conducted with pure Octol to determine the relative rate of dissolution of HMX and TNT. The kinetic experiment was conducted to assess if the disproportion found between these two contaminants was caused by the faster rate of dissolution of TNT compared with HMX.

The main contamination source suspected for antitank ranges are the M72 ammunition by themselves. We have spoken with many CF military and have found that the M72 have a very high dud rate. As it was demonstrated at WATC Wainwright, this ammunition can reach more than 50% "dud producing" rate when fired in the best conditions. This means that many of these duds will break upon hitting targets or rocks and the melt-cast formulation will be exposed to the environment. We have seen many of

these cracked duds on these sites and a picture taken at WATC Wainwright of such a broken M72 is shown at Fig. 15.

6.1 Analysis of Explosives Residues

At CFB Valcartier, although the site had been cleared by safety personnel prior to the characterization, the ground was littered with small pieces of metallic debris from detonated projectiles, empty rocket body, fins and booster cups. A 7 g sample of metallic debris covered with explosives residues was collected and a portion of them were analyzed by FTIR and NMR. The residues were collected and subsequently extracted and analyzed by HPLC. The analytical tests conducted showed that these residues were composed of HMX:TNT:RDX in a proportion of 69:30:1, which corresponds to the formulation of Octol, with the RDX being present as a production impurity in HMX. This proves that pure Octol was present in these metallic debris and that, subsequently, this energetic composition would have been exposed to environmental conditions, leading in the fast dissolution of TNT and accumulation of less soluble HMX at the surface.

6.2 Dissolution Kinetic Study of Octol

In order to demonstrate the difference in kinetic rates of dissolution of HMX and TNT, an experiment was conducted with pure Octol available at DREV to measure the kinetics of dissolution of TNT relative to HMX. Fig. 16 shows the results obtained with this experiment. The results were obtained by placing 44 mg of Octol in 100 ml of distilled water at 25°C and analyzing the aqueous concentration of explosives as a function of time. No agitation was done on the aqueous medium except before taking aliquots to represent at the best the situation in which Octol is exposed to water in the environment. The result clearly demonstrate that TNT dissolves much more rapidly than HMX, which even shows a lag time period before any HMX is detected. Furthermore, the solubility of TNT is much more important than HMX solubility, which also limits the HMX leaching. This explains the disproportion found between HMX and TNT in ATR surface soils.

7.0 CONCLUSION AND RECOMMANDATIONS

Explosive contamination at firing range impact areas was assessed and found to be substantially different than that found on army ammunition plants and depots. HMX is the contaminant found in highest concentration in almost all cases. Contamination is strongly correlated with the locations of targets and the frequency of firing practices, and the contamination is largely concentrated in surface soils. The spatial heterogeneity of analyte concentrations is very large and this is the factor that mostly dominates the strategies to obtain representative samples from these areas. We have found that a combination of homogenization of discrete samples, compositing, and on-site analysis using colorimetric-based methods, is the most effective way to characterize the sites in a cost-effective manner.

We have also demonstrated that the source of contamination on these ranges resides in the type of ammunition fired there. The M72 weapon system has a high dud rate and produces many broken casing that expose the melt-cast explosive Octol on the ranges. This leads to soil and groundwater contamination by both HMX and TNT. This is a very important conclusion since DND must take actions in order to minimize this decremental impact in the future. The best solution would consist in correcting the high dud rate problem of M72 by re-introducing an efficient glazing effect, which would improve the "detonability" of the weapon. Efforts have also to be made to enhance the direct impact "detonability" of the M72 since even when the ammunition hits the target directly, if often does not detonate and this is not acceptable. The fusing system should be modified or replaced by an effective one.

Collecting M72 duds produced after each exercise, would also minimize the leaching process and, therefore, the contamination. If these solutions are not practicable, then Level one clearance should be conducted more frequently. Ideally, the contaminated soils should be remediated since a technology is now available (Ref. 16) and has been demonstrated at CFB Valcartier (Ref. 17). Efforts are now being dedicated to operate this remedial action *in-situ*, which would be the most appropriate scenario for DND.

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Moreover, more data on the environmental fate of explosives in the environment are needed and an effort will be dedicated towards this at an ATR, with a detailed hydrogeological characterization.

8.0 ACKNOWLEDGEMENTS

Range control CF personal of CFB Valcartier, WATC Wainwright and CFAD Dundurn are specially thanked for their precious help and support in all these sampling events. More precisely, we would like to thank Capt Philippe Bérard from CFB Valcartier, Sgt Daniel Dupuis from WATC Wainwright and Chief Warrant Officer Jim Reid from CFAD Dundurn. The authors which also to thank Dr Jacques Lavigne for his precious help in establishing the collaboration between Canadian and American scientists. The Canadian portion of this study was supported by funds from the Directorate of Environmental Protection through the Directorate of Ammunition Program Management. The project team members wish to thank them for their vision and financial support. The US portion of this work was funded by the U.S. Army Environmental Center, Aberdeen Proving Ground, Maryland, Corps of Engineering Services, Sacramento District.

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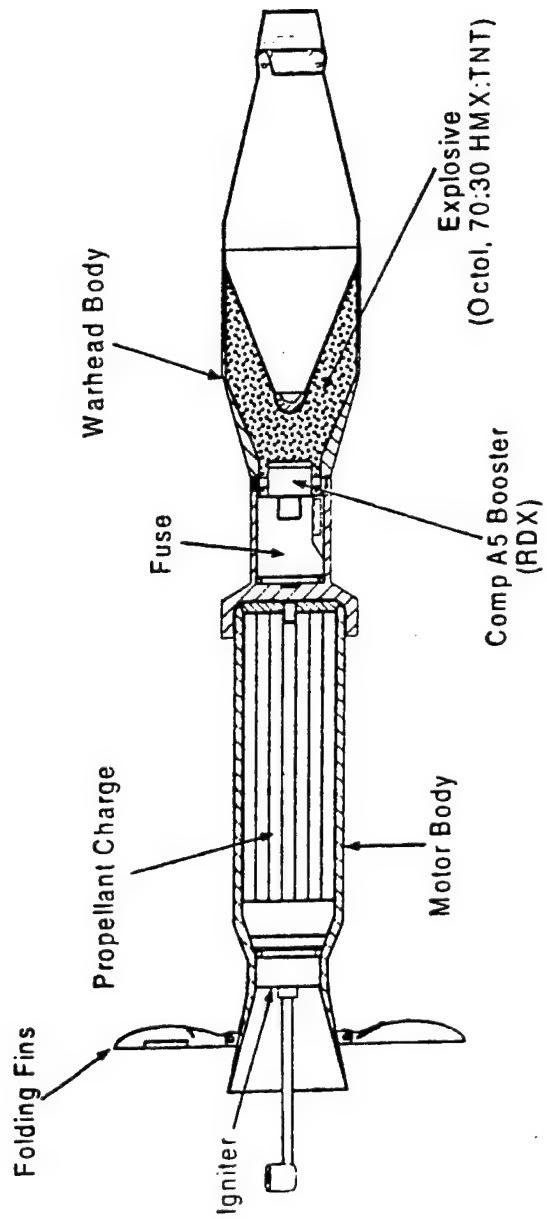


FIGURE 1 – 66-mm M72 weapon system

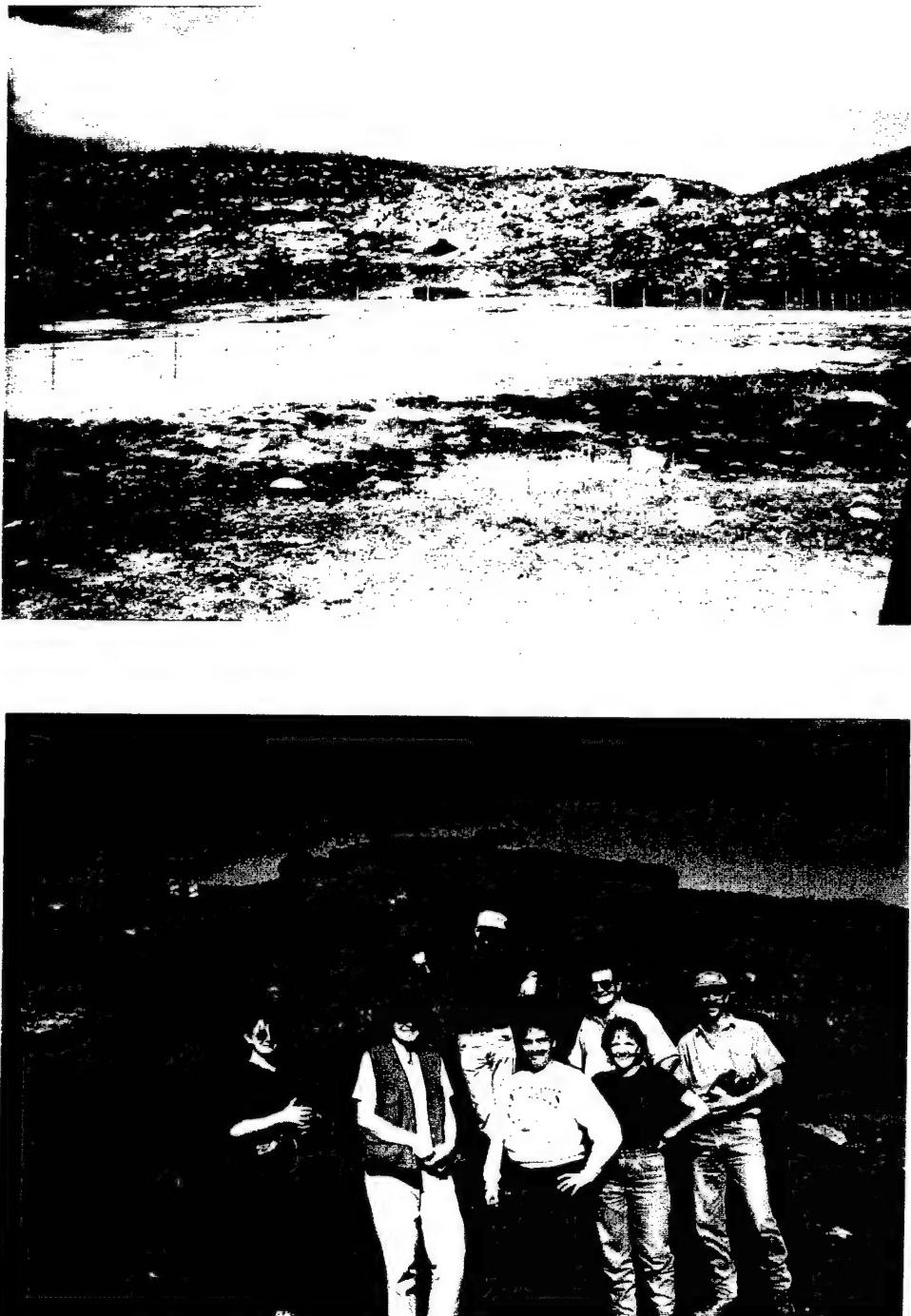


FIGURE 2 - Pictures of Arnhem antitank range

- a) overview of site, b) close view of target D with in order from left to right (first row) :
A. Gagnon, M.E. Walsh, G. Ampleman, S. Thiboutot and A. Marois
(second row): P. G. Thorne and T.A. Ranney.

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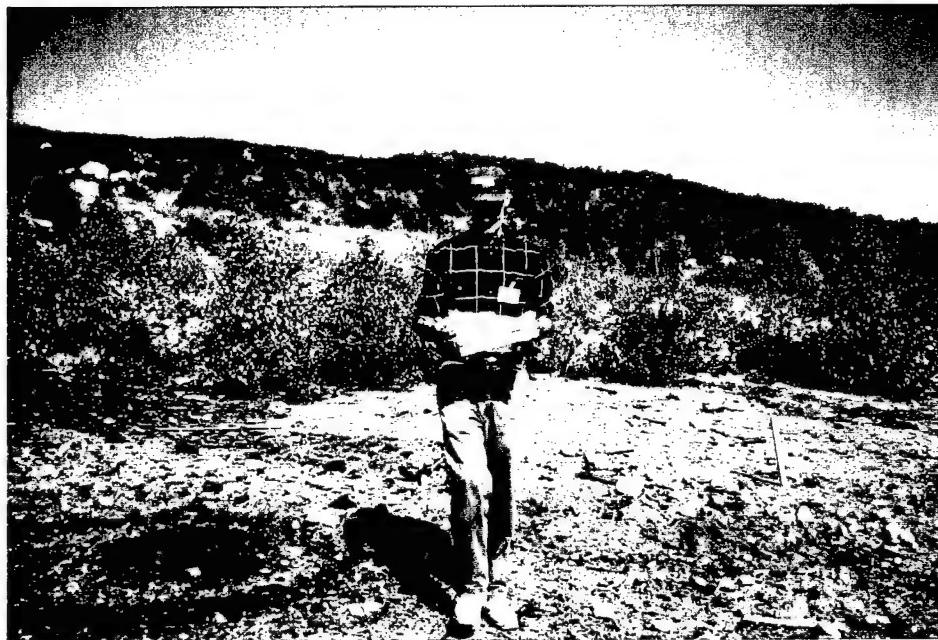


FIGURE 3 - Picture of Dr T.F. Jenkins besides an area integrated sample site

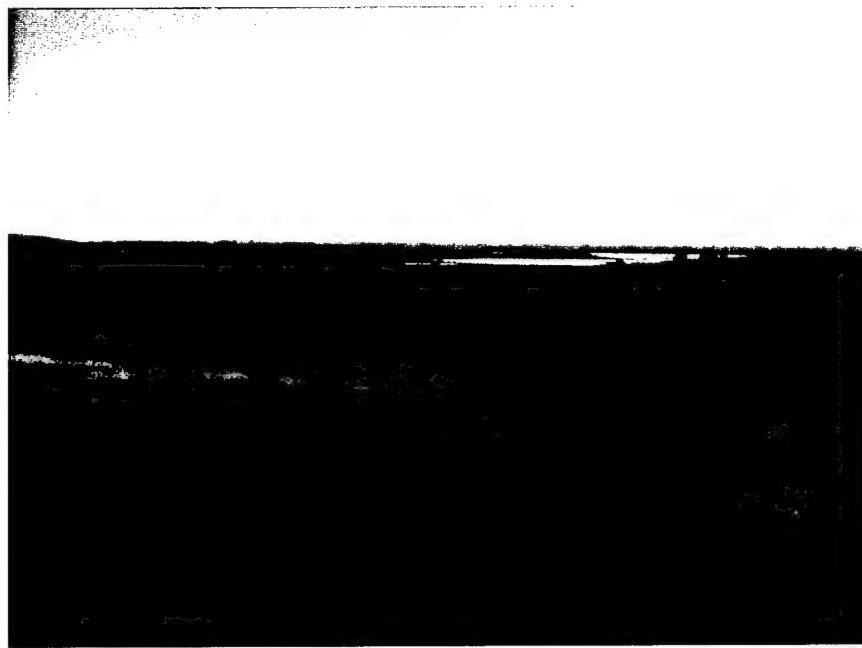


FIGURE 4 - Picture of WATC Wainwright ATR 13

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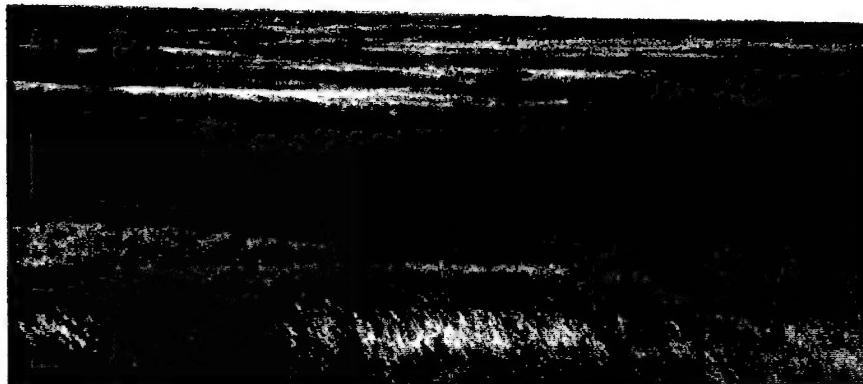


FIGURE 5 - Picture of WATC Wainwright ATR 22



FIGURE 6 - Picture of CFAD Dundurn ATR 2

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FIGURE 7 - Picture of CFAD Dundurn ATR Cougar Range, Target 3

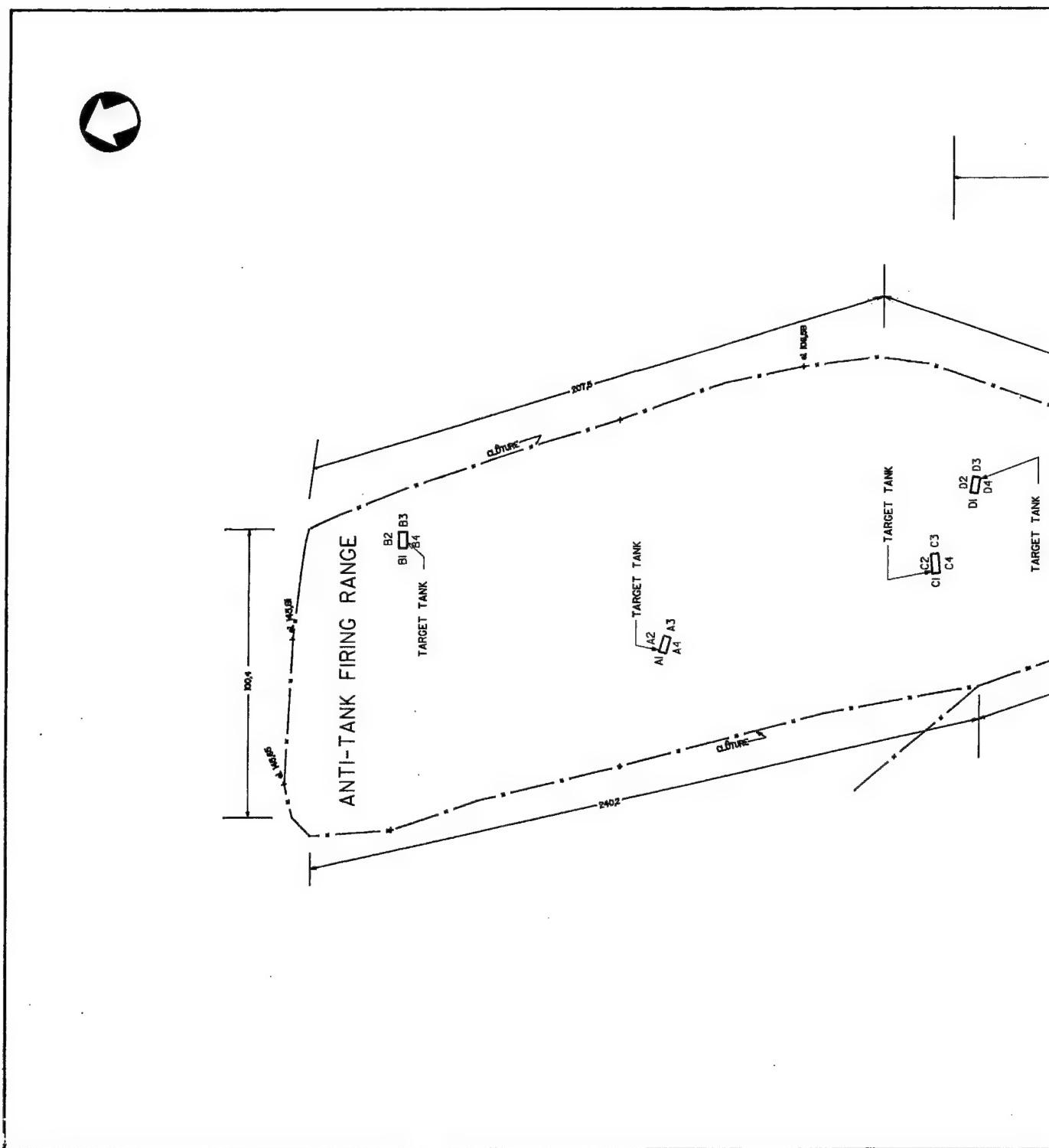
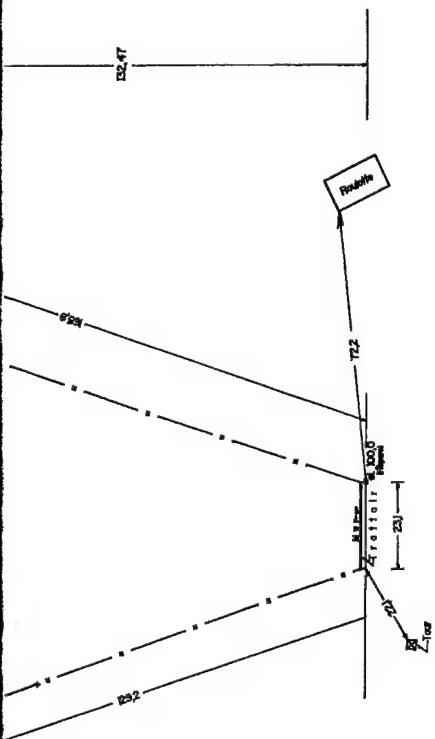
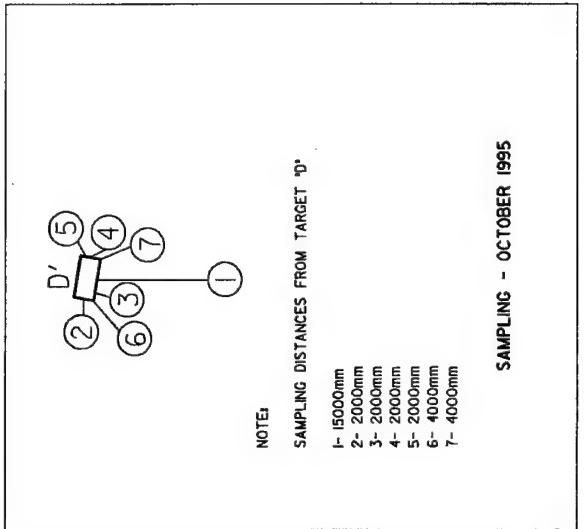


FIGURE 8 - Sampling plan, CFB Valcartier, ATR Arnhem, May and October 1995



SAMPLING - MAY 1995
(2000mm FROM TARGETS)



ARNHEM ANTI-TANK FIRING RANGE

SITE: ARNHEM ANTI-TANK FIRING RANGE

LOCATION: CANADIAN FORCE BASE VALCARTIER

SCALE 1:1000	METRIC MEASUREMENT	DATE OCTOBER 20, 1997	DANIEL DEMERS
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SAMPLE LOCATIONS

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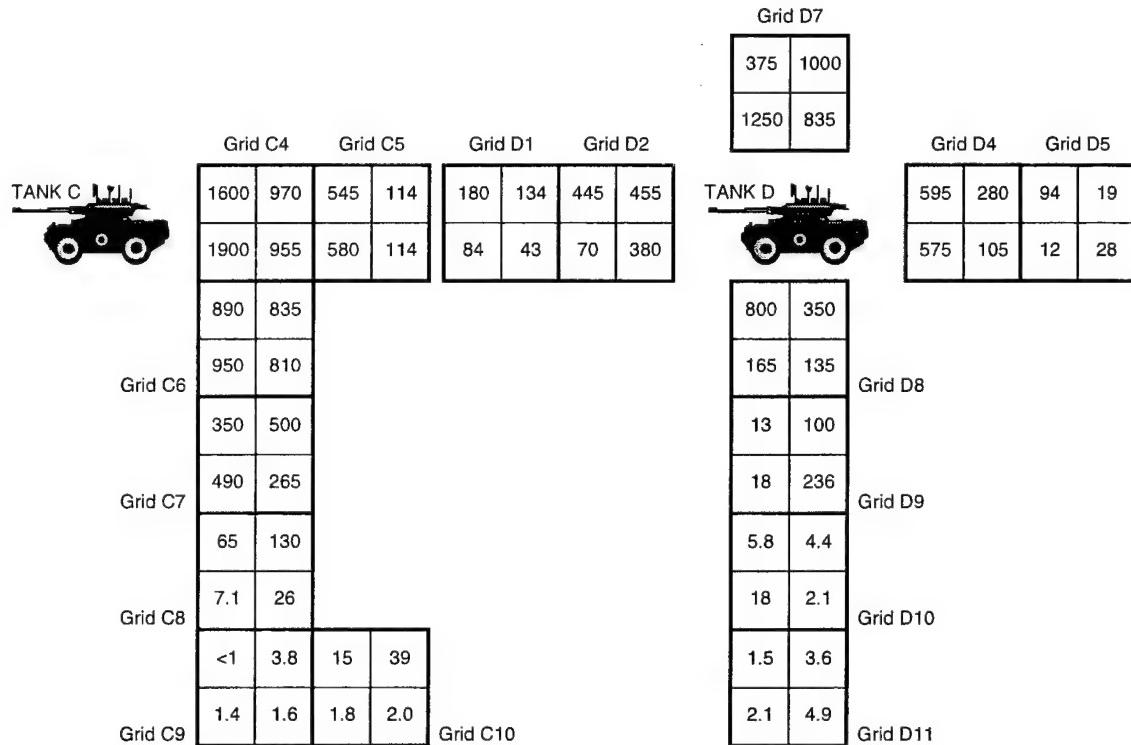


FIGURE 9 - Sampling plan, CFB Valcartier, ATR Arnhem, September 1996

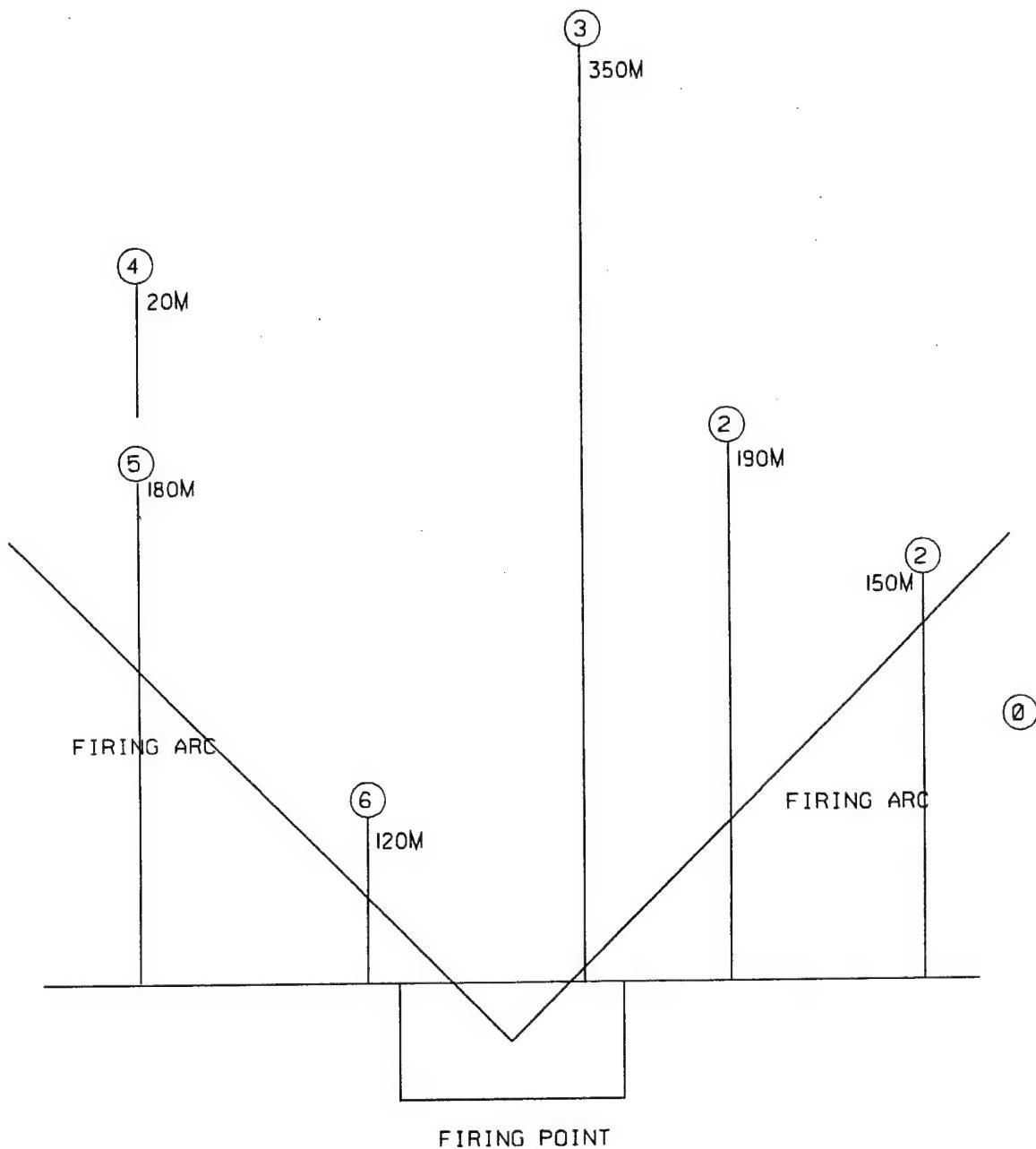


FIGURE 10 - Sampling plan, WATC Wainwright, ATR 13.

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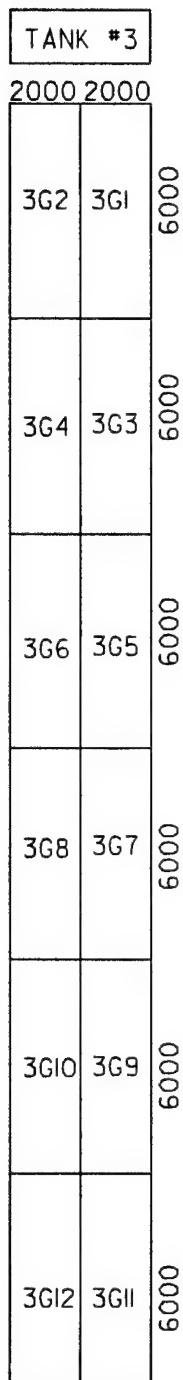


FIGURE 11- Sampling grids in front of Tank 3, WATC Wainwright, ATR 13

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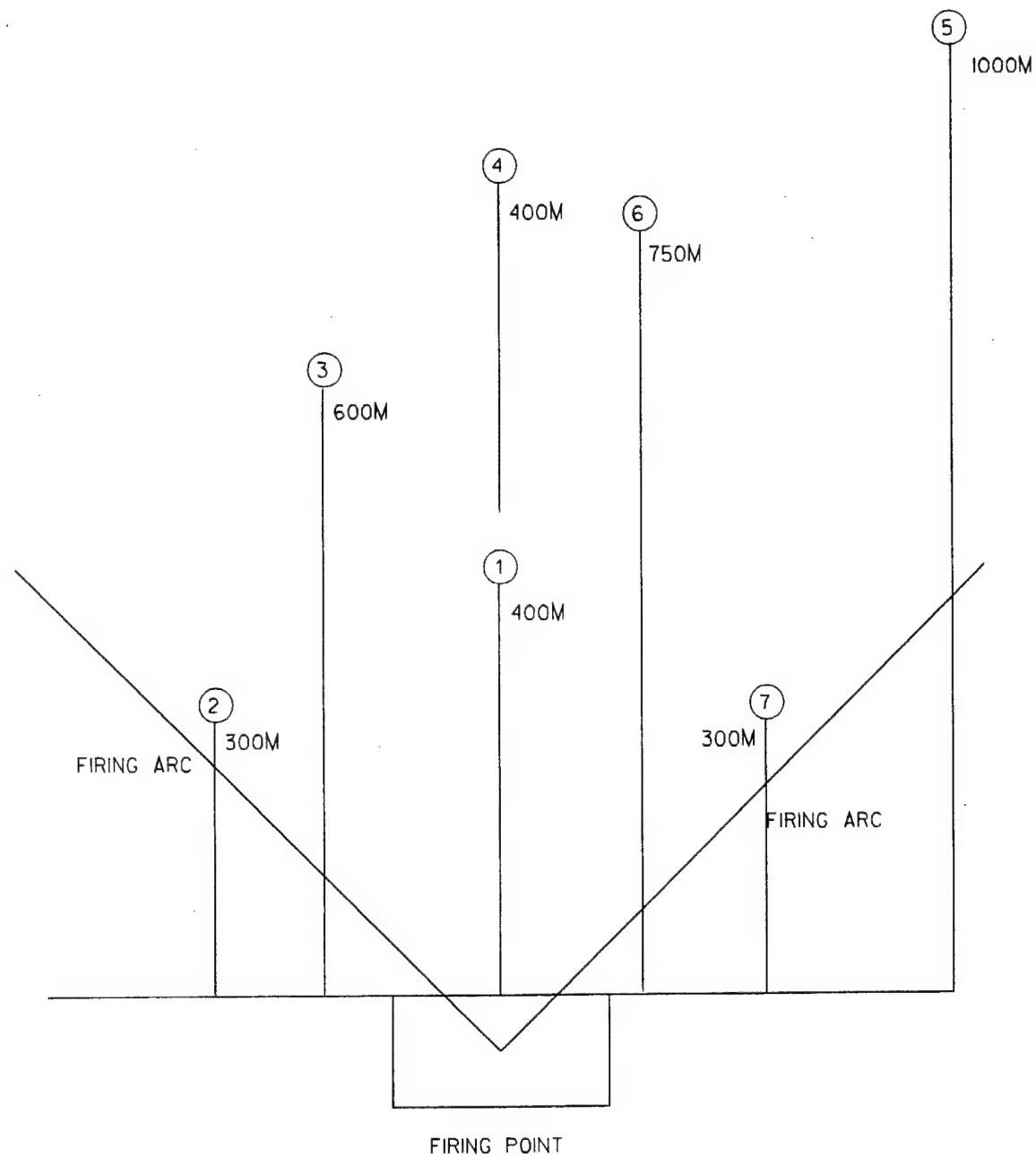


FIGURE 12 - Sampling plan, WATC Wainwright, ATR 22

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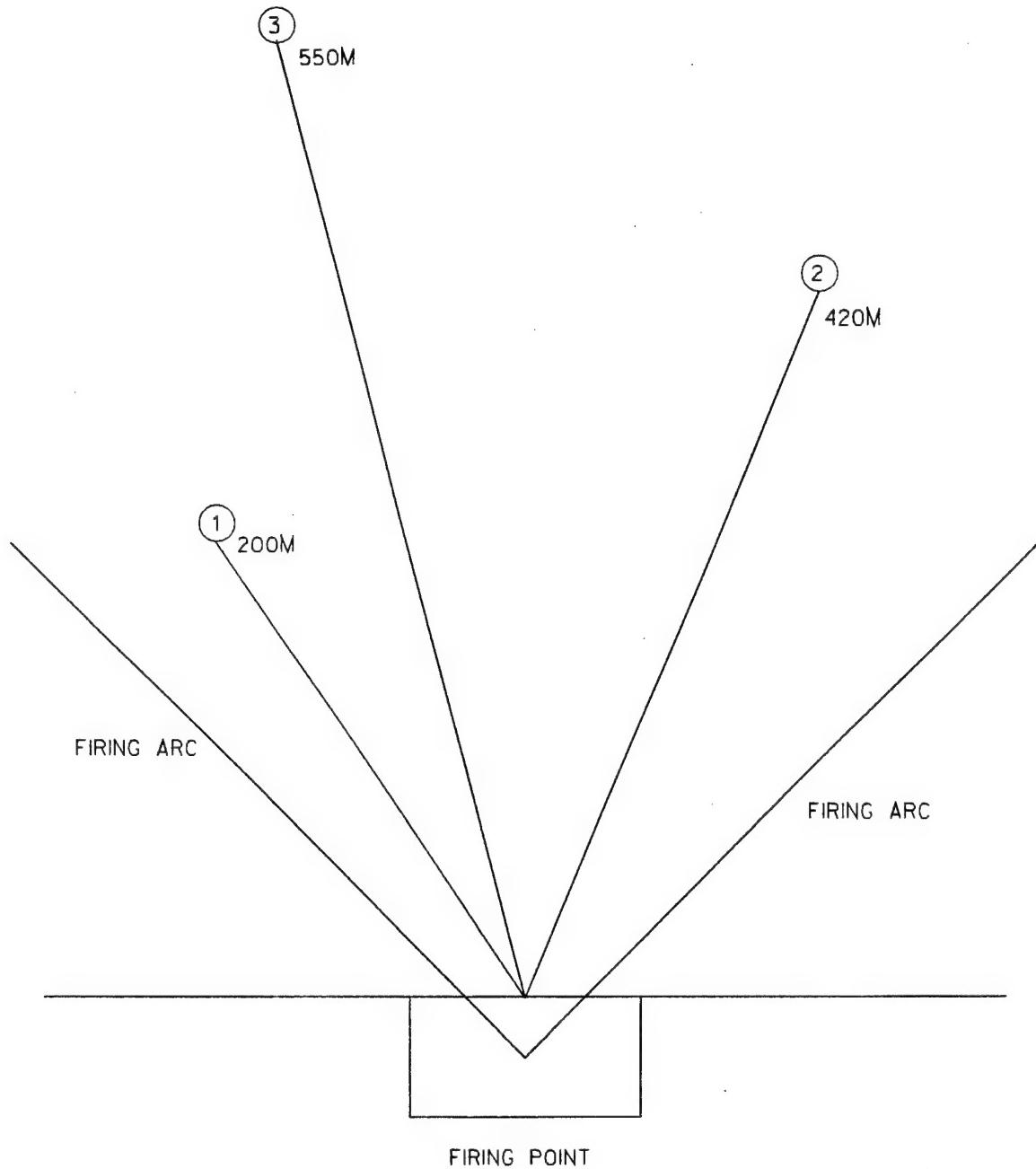


FIGURE 13 - Sampling plan, CFAD Dundurn ATR 2

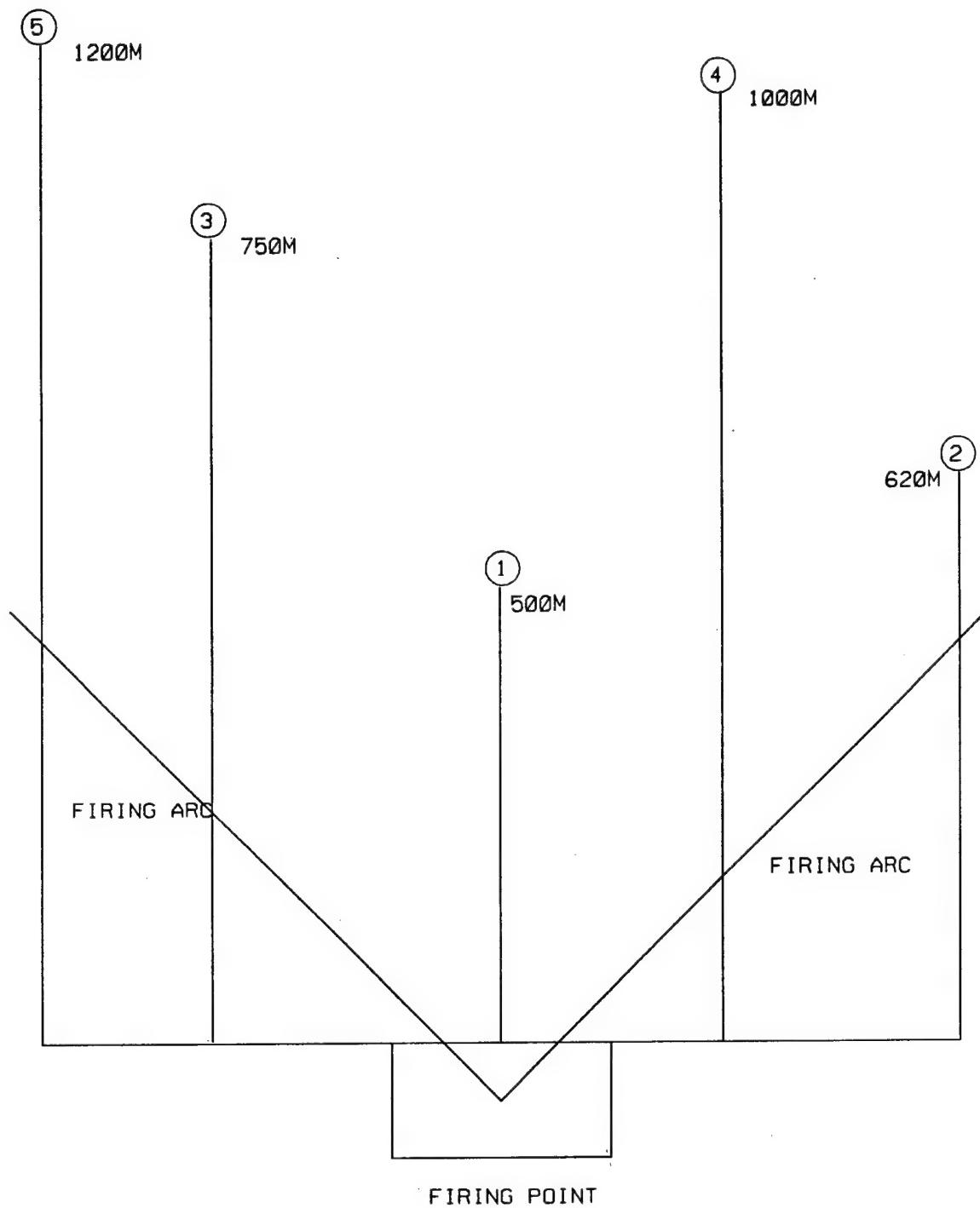


FIGURE 14 - Sampling plan, CFAD Dundurn ATR Cougar Range

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FIGURE 15 - Duds of M72 found on ATR 13, WATC Wainwright

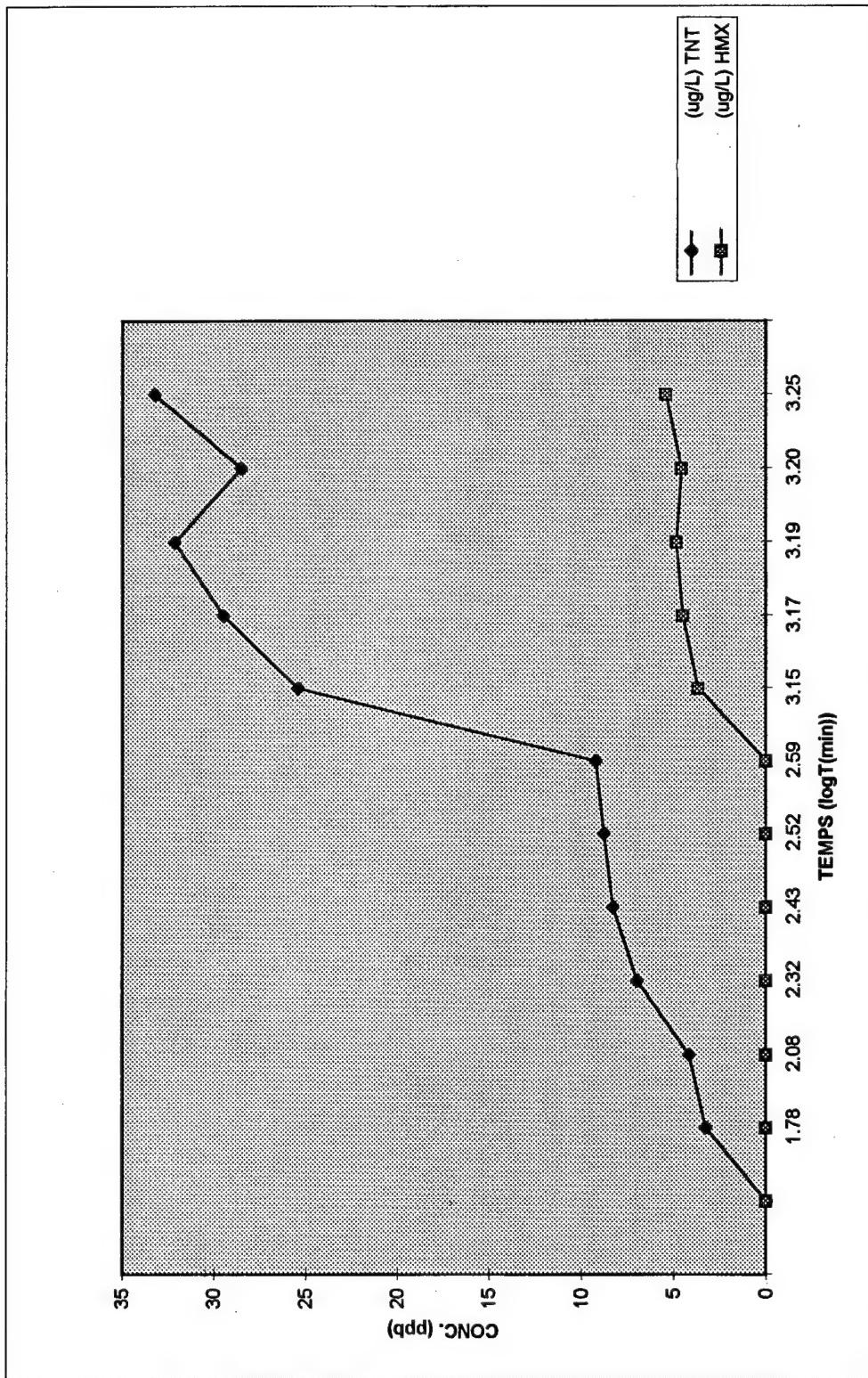


FIGURE 16 - Dissolution kinetics of Octol

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TABLE IAnalytical results: First sampling of Arnhem ATR, May 1995

Sample	HMX (mg/kg)	RDX (mg/kg)	TNT (mg/kg)
A1	354	Nd	0.9
A2	631	11.1	1.8
A3	1868	6.3	37.0
A4	550	1.0	2.0
B1	31	0.4	0.8
B2	166	0.7	1.4
B3	1412	2.3	2.1
B4	259	1.3	0.9
C1	369	21	1.9
C2	16	nd	nd
C3	148	nd	0.9
C4	1687	15.2	137
D1	335	0.4	6.6
D2	252	1.1	4.8
D3	875	1.2	24.7
D4	3899	11.5	159

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TABLE IIAnalytical results: Second sampling of Arnhem ATR, October 1995

Sample	HMX (mg/kg)	RDX (mg/kg)	TNT (mg/kg)
1-10	nd	5.13	nd
1-30	nd	6.94	nd
1-2, 1-4, 1-6, 1-8, 1-12, 1-17, 1-25, 1-33	nd	nd	nd
2-surface	749	nd	4.6
2-1	6.75	nd	nd
2-2	2.73	nd	nd
2-3	nd	nd	nd
3-surface	825	1.9	5.5
3-1, 3-2, 3-3	nd	nd	nd
4-surface	348	nd	3.5
4-1	5.7	nd	nd
4-2, 4-3	nd	nd	nd
5-surface	433	nd	nd
5-1	20	nd	nd
5-2	13.5	nd	nd
5-3	141	nd	nd
6-surface	15.0	nd	nd
6-1, 6-2, 6-4, 6-8, 6-10	nd	nd	nd
7-surface	26	1.6	nd
7-2	nd	1.8	nd
7-1, 7-4, 7-8 7-10	nd	nd	nd

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TABLE IIIAnalytical results: third sampling of Arnhem ATR, Grid C4

Field duplicate	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	1600	nd	8.0	4.2	nd
B	970	nd	16	5.2	nd
C	955	nd	4.8	2.5	nd
D	1900	1.3	10	7.4	0.6
Composite	1400	1.3	3.9	4.0	nd

TABLE IVAnalytical results: third sampling of Arnhem ATR, Grid C5

Field duplicate	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	545	nd	0.8	0.8	nd
B	114	nd	4.8	1.3	nd
C	114	nd	0.8	0.9	nd
D	580	nd	73	nd	nd
Composite	385	nd	4.9	1.7	nd

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TABLE VAnalytical results: third sampling of Arnhem ATR, Grid C6

Field duplicate	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	890	nd	5.0	4.0	nd
B	835	nd	15	2.9	nd
C	810	nd	6.0	2.2	nd
D	950	nd	3.6	3.5	nd
Composite	815	nd	9.0	2.6	nd

TABLE VIAnalytical results: third sampling of Arnhem ATR, Grid C7

Field duplicate	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	350	nd	10	1.0	nd
B	500	nd	3.0	3.0	nd
C	265	nd	nd	1.0	nd
D	490	nd	16	1.9	nd
Composite	380	nd	5.0	1.5	nd

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TABLE VIIAnalytical results: third sampling of Arnhem ATR, Grid C8

Field duplicate	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	65	nd	3.4	0.9	nd
B	130	nd	0.8	1.0	nd
C	26	nd	nd	nd	nd
D	7.1	nd	nd	nd	nd
Composite	66	nd	nd	0.7	nd

TABLE VIIIAnalytical results, third sampling of Arnhem ATR, Grid C9

Field duplicate	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	nd	nd	nd	2.3	nd
B	3.8	nd	nd	nd	nd
C	1.6	nd	nd	nd	nd
D	1.4	nd	nd	nd	nd
Composite	4.0	nd	nd	nd	nd

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TABLE IXAnalytical results: third sampling of Arnhem ATR, grid C10

Field duplicate	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	15	nd	nd	0.5	nd
B	39	nd	nd	0.8	nd
C	2.0	nd	nd	nd	nd
D	1.8	nd	nd	nd	nd
Composite	13	nd	nd	nd	nd

TABLE XAnalytical results: third sampling of Arnhem ATR, Grid D1

Field duplicate	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	180	nd	nd	1.0	nd
B	134	nd	0.6	1.2	nd
C	43	nd	0.4	0.6	nd
D	84	nd	0.3	nd	nd
Composite	86	nd	0.3	0.9	nd

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TABLE XIAnalytical results: third sampling of Arnhem ATR, Grid D2

Field duplicate	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	445	nd	nd	2.1	nd
B	455	nd	1.0	2.5	nd
C	380	nd	3.8	3.6	nd
D	70	nd	0.8	0.9	nd
Composite	270	nd	0.6	2.0	nd

TABLE XIIAnalytical results: third sampling of Arnhem ATR, Grid D4

Field duplicate	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	595	nd	1.3	7.1	nd
B	280	nd	0.7	1.8	nd
C	105	nd	0.6	1.0	nd
D	575	nd	0.6	4.0	nd
Composite	465	nd	0.7	2.4	nd

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TABLE XIIIAnalytical results: third sampling of Arnhem ATR, Grid D5

Field duplicate	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	94	nd	nd	0.7	nd
B	19	nd	nd	nd	nd
C	28	nd	nd	nd	nd
D	12	nd	nd	nd	nd
Composite	31	nd	nd	0.6	nd

TABLE XIVAnalytical results: third sampling of Arnhem ATR, Grid D7

Field duplicate	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	375	nd	1.0	6.0	nd
B	1000	nd	1.8	13	nd
C	835	nd	1.7	8.0	nd
D	1250	nd	9.0	9.0	nd
Composite	830	nd	12	12	nd

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TABLE XVAnalytical results: third sampling of Arnhem ATR, Grid D8

Field duplicate	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	800	nd	21	5.3	nd
B	350	nd	1.1	2.4	nd
C	135	nd	1.3	1.3	nd
D	165	nd	0.9	0.9	nd
Composite	360	nd	2.5	2.5	nd

TABLE XVIAnalytical results: third sampling of Arnhem ATR, Grid D9

Field duplicate	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	13	nd	nd	nd	nd
B	100	nd	0.4	0.8	nd
C	236	nd	nd	nd	nd
D	18	nd	nd	0.4	nd
Composite	34	nd	1.0	2.0	nd

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TABLE XVIIAnalytical results: third sampling of Arnhem ATR, Grid D10

<u>Field duplicate</u>	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	6.0	nd	nd	nd	nd
B	4.4	nd	nd	nd	nd
C	3.2	nd	nd	nd	nd
D	18	nd	nd	nd	nd
Composite	2.7	nd	nd	nd	nd

TABLE XVIIIAnalytical results: third sampling of Arnhem ATR, Grid D11

<u>Field duplicate</u>	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>TNT</u> (mg/kg)	<u>2+4 A-DNT</u> (mg/kg)	<u>TNB+DNB</u> (mg/kg)
A	1.5	nd	nd	nd	nd
B	4.0	nd	nd	nd	nd
C	8..8	nd	nd	nd	nd
D	3.2	nd	nd	nd	nd
Composite	7.9	nd	nd	nd	nd

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TABLE XIXAnalytical results: third sampling of Arnhem ATR, water samples

Sample	HMX (mg/kg)	RDX (mg/kg)	TNT (mg/kg)
Well 1	295*	46*	3.1*
Surface Water 1	125	nd	nd
Surface Water 2	31.7	1.8	nd
Surface Water 3	63*	470*	nd*

* Mean of triplicates

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TABLE XX
Analytical results: Range 13, WATC Wainwright

Sample	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>1,3,5-TNB</u> (mg/kg)	<u>TETRYL</u> (mg/kg)	<u>TNT + a-DNTs</u> (mg/kg)	<u>DNTs</u> (mg/kg)
0	220	nd	0.6	nd	1.3	nd
0 dup	180	nd	0.3	nd	0.8	nd
1A	960	6	0.9	1.1	38	nd
1A dup	790	7	1.0	nd	31	nd
1B	220	nd	0.5	3.4	5.3	nd
1B dup	200	nd	0.3	2.6	3.4	nd
3A	1700	13	1.1	3.5	59	0.3
3A dup	1600	10	1.1	2.8	54	0.4
3AA	3700	13	3.0	4.6	880	1.5
3AA dup	3400	12	4.4	3.9	840	1.4
3B	1600	nd	nd	19	23	nd
3B dup	1500	nd	nd	19	22	nd
3.5	nd	nd	nd	nd	nd	nd
3.5 dup	1.2	nd	nd	nd	nd	nd
4A	36	nd	nd	nd	nd	nd
4A dup	23	nd	nd	nd	nd	nd
4.5	nd	1.4	nd	nd	1.0	nd
4.5 dup	nd	1.3	nd	nd	0.8	nd
5A	210	nd	nd	nd	5.2	nd
5A dup	210	nd	nd	nd	6.8	nd
5B	880	9.9	1.5	1.7	44	0.3
5B dup	810	12	2.4	1.3	49	0.4
6A	120	nd	0.3	3.2	4.1	0.4
6A dup	150	nd	nd	4.8	3.3	nd
6B	1500	9.7	18	13	360	1.8
6B dup	1700	18	45	18	350	2.1

dup: lab duplicates,

NB, 1,3-DNB, 2-NT, 3-NT AND 4-NT not detected (nd)

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TABLE XXIAnalytical results: Range 13, WATC Wainwright, grids south of Target 3

<u>Sample</u>	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>1,3,5-TNB</u> (mg/kg)	<u>TETRYL</u> (mg/kg)	<u>TNT + a-DNTs</u> (mg/kg)
3G 1	1200	10	1.1	5.6	45
3G 1 dup	1200	16	2.1	6.9	59
3G 2	780	3.2	0.4	14	23
3G 2 dup	540	3.3	0.5	9.4	22
3G 3	360	2.3	0.3	2.1	13
3G 3 dup	250	2.0	0.3	1.7	12
3G 4	nd	nd	nd	nd	nd
3G 4 dup	nd	nd	nd	nd	nd
3G 5	83	nd	0.3	nd	4.2
3G 5 dup	94	nd	0.3	nd	4.8
3G 6	87	nd	nd	9.4	5.5
3G 6 dup	96	nd	nd	16	9.8
3G 7	120	1.2	nd	0.9	4.7
3G 7 dup	110	2.0	0.3	1.5	6.4
3G 8	540	1.9	0.8	0.9	57
3G 8 dup	490	2.0	0.8	nd	45
3G 9	32	8.4	nd	nd	3.4
3G 9 dup	43	11	nd	nd	5.0
3G 10	85	5.8	nd	nd	5.0
3G 10 dup	98	5.5	nd	nd	4.7
3G 11	55	2.3	nd	nd	nd
3G 11 dup	51	2.8	nd	nd	0.5
3G 12	92	3.1	0.8	nd	10
3G 12 dup	98	4.0	0.9	nd	11

NB, 1,3-DNB, DNTs, 2-NT, 3-NT and 4-NT not detected (nd)

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TABLE XXIIAnalytical results: Range 22, WATC Wainwright

<u>Sample</u>	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>1,3,5-TNB</u> (mg/kg)	<u>TNT + a-DNTs</u> (mg/kg)	<u>DNTs</u> (mg/kg)
1A	76	1.3	0.7	1.9	nd
1A dup	83	nd	1.0	2.2	0.4
1B	290	5.7	3.8	68	nd
1B dup	260	6.0	3.8	56	nd
3A	2.2	1.2	nd	nd	nd
3A dup	2.4	1.5	nd	nd	nd
3B	4.9	5.0	nd	nd	nd
3B dup	6.2	5.2	0.3	nd	nd
4A	1.9	nd	0.5	nd	nd
4A dup	2.1	1.4	0.4	nd	nd
4B	nd	nd	0.4	nd	nd
4B dup	nd	nd	nd	nd	nd
7A	3.3	1.1	nd	nd	nd
7A dup	3.1	nd	nd	nd	nd
7B	5.2	nd	nd	nd	nd
7B dup	5.7	nd	nd	nd	nd

NB, 1,3-DNB, 2-NT, 3-NT and 4-NT not detected (nd)

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TABLE XXIIIAnalytical results: Range 2, CFAD Dundurn

<u>Sample</u>	<u>HMX</u> (mg/kg)	<u>1,3,5-TNB</u> (mg/kg)	<u>TNT + a-DNTs</u> (mg/kg)
1	98 (103)	0.3	nd
1 dup	120	0.4	nd
2	nd (nd)	nd	0.5
2 dup	nd	Nd	0.4
3	18 (18.8)	Nd	0.6
3 dup	23	Nd	0.6

RDX, 1,3-DNB, Tetryl, NB, DNTs, 2-NT, 3-NT and 4-NT not detected (nd)

() : results of field colorimetric results

TABLE XXIVAnalytical results: Cougar Range, CFAD Dundurn

<u>Sample</u>	<u>HMX</u> (mg/kg)	<u>RDX</u> (mg/kg)	<u>1,3,5-TNB</u> (mg/kg)	<u>TNT + a-DNTs</u> (mg/kg)
1	1.8 (1.3)	3.5	0.4	nd
1 dup	1.3	2.0	nd	nd
2	1.0 (1.8)	1.0	nd	nd
2 dup	1.0	2.0	nd	nd
3	21 (91)	89	nd	0.5
3 dup	20	85	nd	0.7
5	nd (1.4)	1.4	nd	0.4
5 dup	nd	1.5	nd	nd

1,3-DNB, Tetryl, NB, DNTs, 2-NT, 3-NT and 4-NT not detected (nd)

() : results of field colrimetric method

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Some operational activities of the Canadian Forces such as firing practice may lead to the dispersion of energetic compounds in the environment. These compounds are being closely examined due to their highly specific physical, chemical and toxicological properties. In Canada, limited effort has been spent to examine this particular environmental threat. In this context, the characterization of many firing ranges potentially contaminated with explosives have been performed in the last few years. Air to soil ranges and soil to soil ranges have been characterized and in general, low levels of multi-contamination by explosives were found. However, antitank firing ranges samples showed high levels of contamination by HMX, a high explosive used in many antitank rockets. The present report details the characterization of five antitank ranges located at Canadian Forces Base Valcartier, Western Area Training Center Wainwright and Canadian Forces Ammunition Depot, Dundurn. The sampling and analytical methods are described and results are presented. This work will help the Canadian Forces to pursue their operational activities while minimizing impacts on the environment by leading to a better comprehension of the source of contamination and helping to minimize environmental impacts in the future.

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